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A FRAMEWORK FOR REACHING COMMON UNDERSTANDING DURING SKETCHING IN DESIGN TEAMS

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1. Introduction

Freehand sketching has traditionally been used as a primary conceptual tool in the early stages of a design process [Fish and Scrivener 1990]. It is commonly leveraged to structure problems, generate and explore solutions, investigate functions or/and forms, and thus, to assist designers to develop and analyse ideas. This cognitive facet has been emphasised by Cross, who refers to the memory saving aspect of sketching, when he points out, "Sketches enable designers to handle different levels of abstraction simultaneously" [Cross 2006].

Nowadays, most design activities are taking place in teams, and require the individual designer to communicate his/her own views about the problem and solution spaces to other team members. However, these ideas are often not well formulated and fuzzy upstream in the design process, and need more processing to become more transferable. Naturally, this task is even more demanding in interdisciplinary teams. Differences in goals, languages, and other cultural variables produce conflicting views which needs to be synchronized [Smulders 2008] to make design decisions. In general, designers are trained to support their verbal explanations by visual representations in order to facilitate communication and mutual understanding, or vice versa.

During the embodiment and detail design phases sketching does not have the same relevance, but can still useful in order to resolve details which cannot be addressed by verbal description communication only. Moreover, sketches play a critical role in communicating with an external audience, such as during a presentation.

Pipes refers to three essential functions of sketching —"a designer's drawing"—in situations of information transfer as follows:

1. It is a means of externalizing and analysing thoughts and simplifying multi-faceted problems to make them more understandable,
2. It is a medium of persuasion that sells idea to clients, and reassures them that their brief will be understood correctly,
3. It is a method for communicating complete and unambiguous information to those responsible for the product's manufacture, assembly and marketing" [Pipes 2007, p.15].

1.1 Sketching in design teams

Design concepts, even while being created, often constitute artefacts that resemble objects in the real world. Designers hold mental images of these artefacts that assist them during their thinking process [Athavankar 1997]. These mental images have to be manipulated and altered constantly during the design process. Although the preconditions and circumstances in which sketching is required is not yet

fully understood, there seems to be an unproven belief that designers often use sketches to facilitate thinking. It has been shown that sketching does not necessarily lead to a better results [Bilda et al. 2006].
However, in summary, most empirical studies reveal that sketching is a necessary part of the design process [Ullman et al. 1990]. In addition to the functions referenced above (as identified by Pipes), we can also state that:

1. The use of visual representations by sketching provides a memory extension which lowers the cognitive load [Purcell and Gero 1998]. Therefore, designers who sketch during the design process perceive problems as less difficult, and can infer more relations between components of complex concepts [Sachse et al. 2004]. These results support the idea that sketches contribute to a better and deeper understanding of one's own ideas.
2. During design collaboration the use of shared sketches within the design team facilitates communication by providing a common ground that contributes to a shared focus of attention and understanding [Heiser et al. 2004].

1.2 Research questions

In this paper, we investigate the following questions:

- How are ideas transferred within a design team when verbal communication is blocked?
- How does information transfer during sketching change if verbal communication is blocked?

2. Empirical study

2.1 Method and data collection

The study was executed as quasi-experiment study. The participants were 18 Master design students from the Faculty of Industrial Design Engineering, Delft University of Technology. Two experiments were done with 3 groups of 3 participants for the control group and the experimental group. For the experimental group the task was that the groups had to perform a design task but they were not allowed to speak to each other during designing, which we call the "silent sketching" group and participants in the control group, they underwent the same design task without any limitation. This group is named as "non-silent sketching" group. Both groups were assigned to 2 phases of the design task.

2.2 The design task

As shown in Figures 1 and 2, the experiment was divided into two phases. In the first phase, the groups were given 45 minutes to generate ideas. The task was to design a product that helps blind people to cook. The teams were given 5 minutes for reading the design brief and in the next 10 minutes, each participant had to work individually to generate his/her own ideas without contacting the other group members – this condition was the same for the experimental and control groups. After that, the group members worked together and developed a final concept.
After a 10 minute break, the second phase started, which was intended as the "stimuli phase." A new set of instructions were provided to groups, which further specified the goal by stating "camping" as the context in which cooking takes place. The new instructions also contained pictures of existing outdoor cooking utensils as stimuli. The intent of the stimuli was to narrow down the solution space and to facilitate the process of reaching common agreement. In this phase, the groups had to complete the design task in 25 minutes, with 5 minutes for reading the instructions and 20 minutes for group work. In the last 5 minutes of the experiment, groups presented their final idea. A survey to assess the communication medium preference (sketch, written, and verbal) was administered to all participants before the task. All activities and the resulting sketches were video recorded, observed and analyzed.

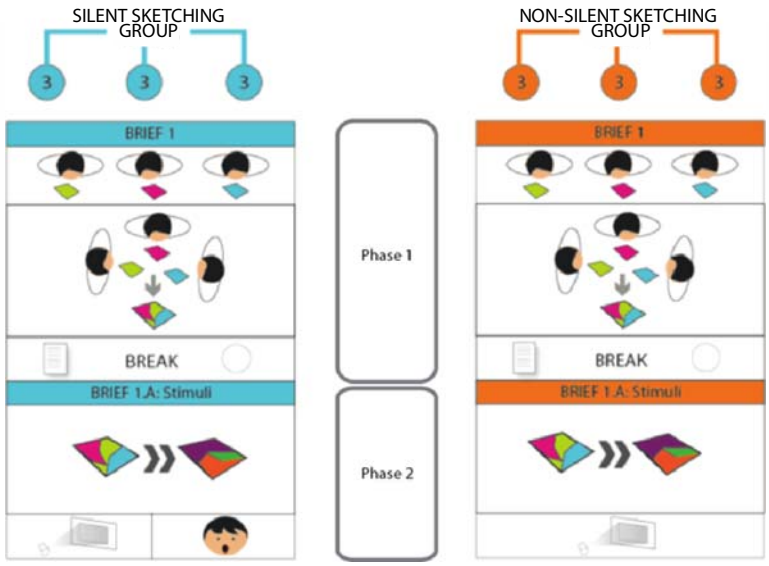


Figure 1. Overview of experiment

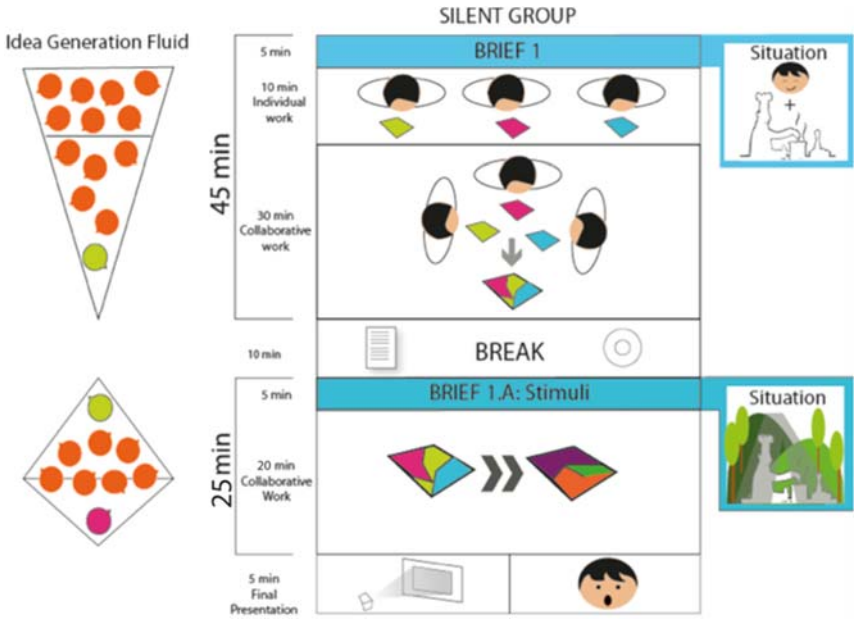


Figure 2. Overview of sketching task

2.3 Activity categorization

Sketches were analyzed according to following four activity categories:

- Drawing (DWg)
- Detailing (DTg)
- Explaining (EXg)
- Transferring (TRg)

There are two types of sketch elements; 'support notation' which includes textual notes, list dimensions (leaders and arrows) as well as calculation; and, 'graphic representation', which includes, drawing of objects and their functions, plots and charts [Ullman et al. 1990].

Based on this understanding and our own analysis of sketches generated in design activity, we developed a new framework for categorizing sketch elements and expressed them in the form of a design-communication block (Figure 3). The element categories are drawing, supporting, technical, explanation and conversation.

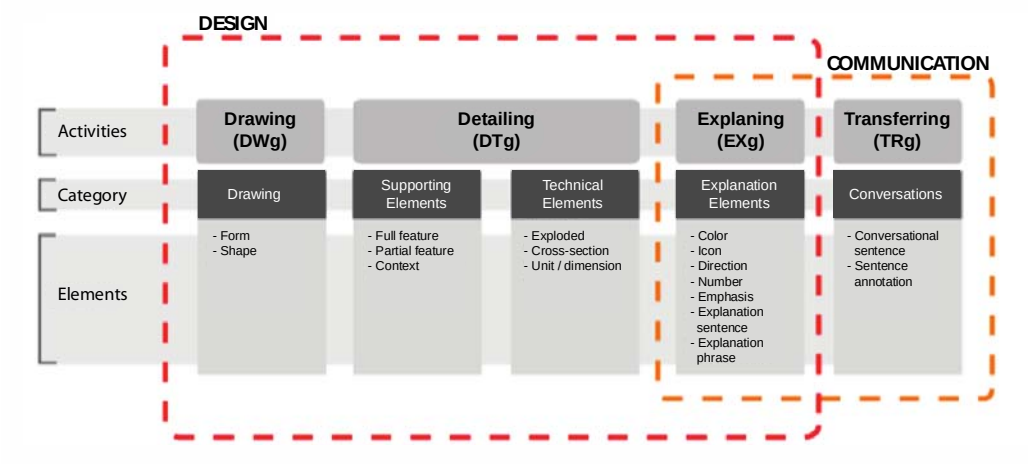


Figure 3. The Design-Communication block framework

The Design-Communication block framework dimensions and sketch elements are defined in detail on Table 1. We used these definitions as guidelines for coding and counting the sketch elements that were created during the experiments. Although we discuss the entire Design-Communication block framework here, this paper is focused on the activities associated with the design block only.

Table 1. Definitions the design-communication block framework dimensions

Activities	Element of categorizations	Elements
Drawing (DWg) Drawing/sketching on paper.	**Drawing Elements :** Elements of a drawing that communicate functionality at the level of a product and have distinct physical forms (such as a stove, pot, sink).	**Sketch :** Sketch elements with low level of detail and high level of ambiguity. **Form :** Sketch elements with high level of detail and low level of ambiguity.
Detailing (DTg) Extending/refining a drawing element through the use of supplemental drawing or technical elements.	**Supporting Elements :** Drawing elements that re-visualize an existing drawing element in additional detail.	**Full feature :** An additional and more detailed drawing of an entire existing drawing element. **Partial feature :** An additional and more detailed drawing of a part of an existing drawing element. **Context :** An additional drawing of an existing drawing element in a specific context--often to visualize a usage scenario.
	Technical Elements : Technical elements that convey a technically detailed understanding of existing drawing elements.	**Exploded :** Exploded view of an assembly that further specifies its geometry. **Cross-section :** Cross sectional view of a part that further specifies its geometry. **Unit/dimension :** Value and/or units of technical parameters such as length (m) or 10 m.
Explaning (EXg) Annotating existing drawing elements with graphical, numerical, or textual information to clarify their meaning.	**Explanation Elements :** Elements that clarify the meaning of existing drawing elements in the form of annotations.	**Color :** Use of color to indicate meaning. (For example, red is hot.) **Icon :** A graphical symbol commonly understood within the group that is used to identify or communicate meaning. Can be very general such as the addition symbol "+", or can be internal to the group such as the group creating an icon to represent blind people. **Direction :** Lines that indicate direction (such as an arrow) from one point/area to another point/area on the drawing. **Number :** An arithmetical value, expressed by a word, symbol, or figure, that is used to calculate, order in a series, or to identify. **Emphasis :** Special importance or prominence given to a drawing element such as underlining. **Explanation Sentence :** A note written in the form of a sentence to further explain a drawing element. **Explanation Phrase :** A brief textual annotation used to explain a drawing element.
Transferring (TRg) Carrying out a conversation to establish common understanding within the group around the drawing elements.	**Conversation Elements :** Elements enable written communication on the meaning of existing drawing elements.	**Conversational Sentence :** A note written in the form of a sentence to further explain a drawing element. **Sentence Annotation :** A brief textual annotation used to explain a conversational sentence.

2.4 Visual connectivity analysis

In order to understand how ideas were transferred within the group through visual communication, we analysed how drawing elements that were created during the individual part of the experiment were connected with the drawing elements that were created during the collaborative part. Sketches created after the stimuli were not a part of this analysis because the relationships between the sketch elements could not be reliably tracked that far into the design process. Figure 4 graphically illustrates the outcome of that analysis for one of the silent groups.

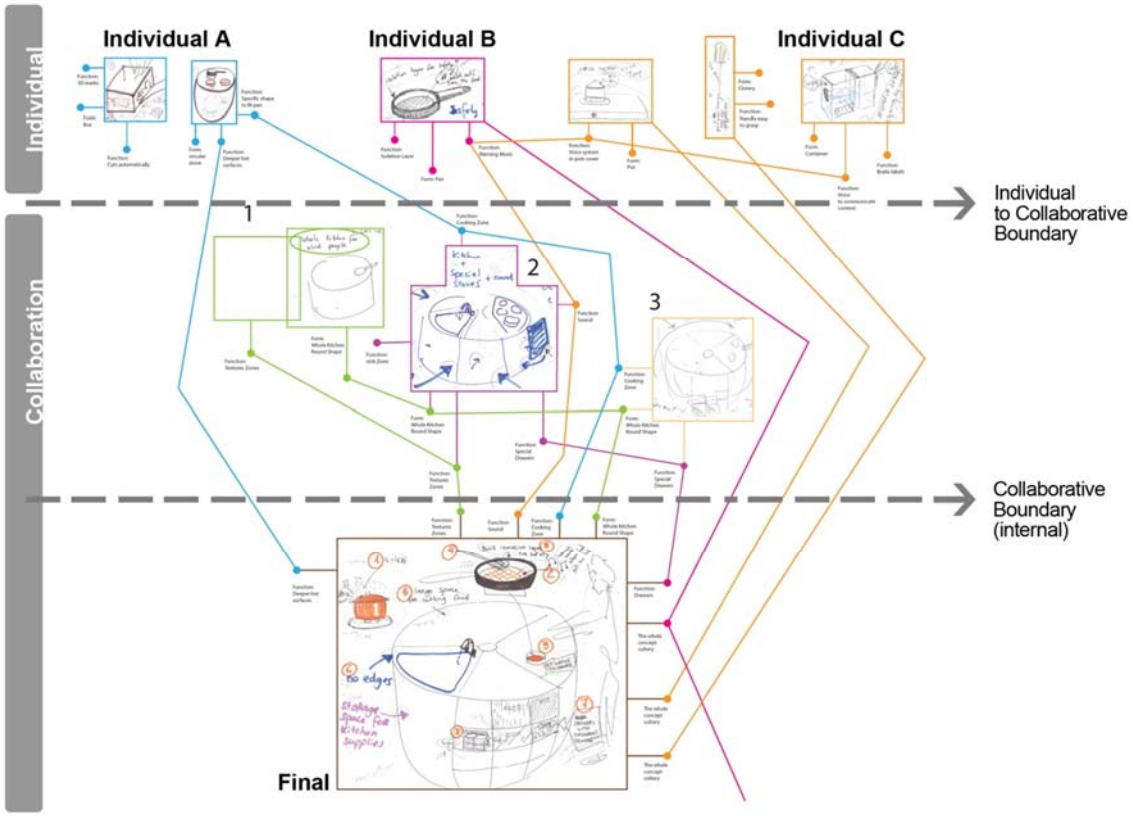


Figure 4. Outcome of the visual connectivity analysis for one of the silent groups. Lines indicate links that show either a form or function relationship between two sketch elements

The lines represent "visual links." We associated each sketch element with a form (graphic), and one or more function (to the extent that it/they are revealed by the graphic). Sketch elements in the different parts of the design process sharing the same form or function were assumed to be "connected," and lines across the sketch elements depict such connections. We paid specific attention to how sketch elements were connected across two boundaries; 1) individual to collaborative boundary and 2) collaborative boundary (internal of the collaborative activity). The collaborative boundary is established between the drawings that appear in the final proposal and the group activity that preceded it. These distinctions allowed us to investigate the effects of blocking verbal communication on how ideas were shared within the team.

3. Results

In this section, we present the results of the three types of analysis outlined in section 2: categorisation of the sketching activities, visual connectivity analysis, qualitative observations on the design-communication block activities, and the communication methods preference survey. We have not conducted statistical analysis to test for the significance of the differences that exist between the silent

and non-silent groups because the number of groups in each experimental condition is small (n=3) at this point in the project.

3.1 Categorisation of sketching activities

A total of 60 A3 size paper sheets with sketches were collected during the experiment. 23 sheets were from the non-silent sketching group, and 37 sheets were from the silent sketching group.
The main evaluation of the sketches was done by identifying the elements in the sketches and grouping them into the categories discussed in section 2. Sketching activities were counted and summed per experimental condition. Results are shown on Table 2.

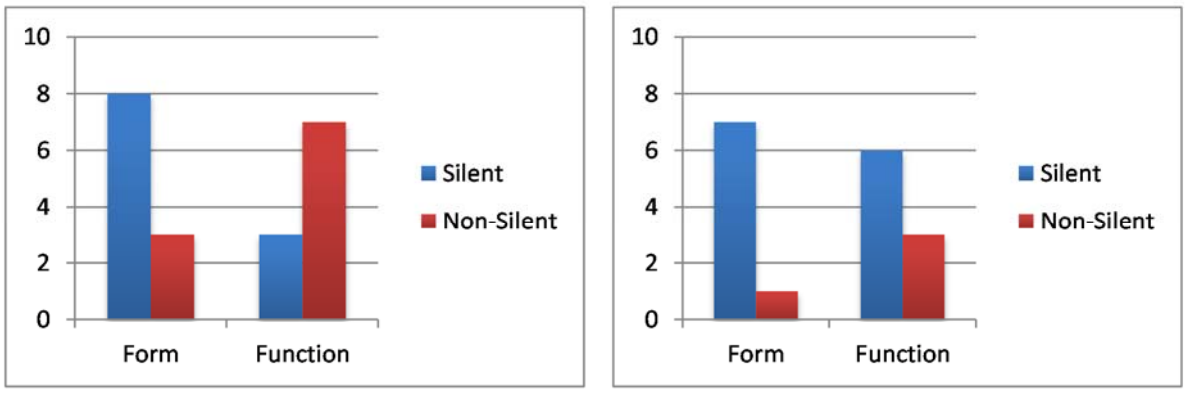
Table 2. Differences between silent and non-silent group according to four main activities

Activities		Group	
		Silent	Non Silent
Drawing	Count	**40**	**40**
	% of total	4.3%	17.8%
Explaining	Count	**716**	**150**
	% of total	77.3%	66.7%
Detailing	Count	**43**	**16**
	% of total	4.6%	7.1%
Transferring	Count	**127**	**19**
	% of total	13.7%	8.4%
Total	Count	**926**	**255**
	% of total	**100%**	**100%**

As can be seen on Table 2, although both conditions yielded the same number of drawing elements, the silent conditions yielded much higher explanation, detailing, and transferring elements.

3.2 Visual connectivity

The link counts that cross the individual to collaborative boundary are indicated on the graph on the left in Figure 5. The link counts that cross within the collaborative boundary are indicated on the graph on the right in Figure 5. As defined in section 2, each link was further categorized into a form or function link. Links that went from the individual activity directly to the final product were not included in this analysis.



Individual to collaborative link counts **Collaborative links (internal) counts**

Figure 5. Results of visual connectivity analysis for the silent and non-silent sketching groups

Link counts across the individual to collaborative boundary suggest an interesting trend: silent groups made more form connections whereas non-silent groups made more function connections. This suggests that when verbal communication was blocked, form elements were the more tangible elements for describing the drawing, and thus, use for transfer within the group. Furthermore, form elements can visualize the idea(s) more effectively, which later seed the graphical dialog within the team.

For the non-silent sketching groups, function elements seemed to be mechanism for describing the drawing in order to bring the idea(s) forward into the collaborative activity. Therefore, verbal language might be playing a role in allowing the team to explore and leverage the semantics of the sketch elements.

However, a different pattern appeared within the collaborative activity when links across the collaborative boundary were analysed: Silent groups made more both form and function connections. This might be because of the increased relevance of exploring function while trying to converge on a final solution, which applies to either group. And since the non-silent groups cannot use verbal language to accomplish that, it is possible that they use the only communication medium that is available to them. In other words, even when verbal communication is blocked, function elements were used in conjunction with form elements during the collaborative activity when the need to establish common understanding was critical.

3.3 Qualitative observations on the design-communication block activities

During the first part of the experiment, designers were asked to generate and sketch solution ideas individually in response to the design brief. These sketches were then brought into the group. The teams paid special attention to the drawing elements (form and shape), which were initially fairly abstract for the purposes of transferring individual ideas to other group members and moving toward a decision about the proposed solution. The need to produce a final concept by the end of the session drove the detailing of the form and shape of drawing elements in order to anchor the description of the ideas under consideration. Therefore, as more elements were gathered and sketched, the proposed concept became more concrete until it was finalized.

Figure 6. Framework for reaching common understanding during sketching in design teams

Figure 6 illustrated the process that relates the four activity categories – drawing (DTg), detailing (DTg), explaning (EXg) and transferring (TRg). Drawing appeared to be continuous activity throughout the design task, whereas detailing, explaining and transferring activities built on drawing elements in order to negotiate and develop the idea(s); they ensured that the ideas were transferrable to the team. Transferring activities can be considered be effective when common understanding of a given idea is established across the team.

Therefore Figure 6 depicts a cycle (the green arrows) that builds on and revolves around drawing activity (the orange arrows). It can be argued that as the team executed that cycle in an iterative fashion, the level of ambiguity in the drawing elements decreased and the ideas became more concrete.
In producing the final concept, these four activities were performed in both experimental conditions – silent and non-silent groups. However, as shown on Table 2, it is interesting to note that both groups created a similar amount of drawing elements. Therefore, the difference was in what was happening *around* the drawing activity.

3.4 Communication preference survey

A survey was administered to assess the communication medium preference (sketch, written, and verbal) of all participants before the task. More specifically, participants were asked how comfortable they feel with each medium to convey their ideas. The instrument utilized a 5-point response scale, where 1 represented "not comfortable at all," and 5 represented "very comfortable." The survey also contained an item asking if the participants had received formal sketching training, with "Yes" or "No" response options.
All 18 participants have formal sketching experience. Responses to the communication medium preference items were analysed per study group. An ANOVA was conducted to identify any significant differences between the groups. There were no significant differences between the six study groups.

4. Conclusion

Sketching is a powerful tool for designers to visualize and transfer their ideas. Yet, to make the ideas more transferrable and clear to the other designers in a team, verbal communication is needed; language seems to be a necessary way to transfer details. Our findings show that although drawing activity itself forms the basis of discourse, explaining, detailing and transfer activities make ideas more concrete, understandable and transferrable within the team. This is in line with the previous finding where sketches have been found to result in a more integrated group process [Van Der Lugt 2005]. Our findings also show that when verbal communication is blocked, the distinction between drawing and explaining, detailing and transfer activities become even clearer.
Building on that, team members do not only develop shared mental models about the task at hand but also about the process and the team as they need to guide their group process accordingly. Doing so, they need a good understanding of each other's perspectives and what they are working on at the moment. This finding is also in line with one of our previous findings, that the common sketching and use of sketches in the team as a common ground can help to create shared mental models [Neumann et al. 2009].
Based on these outcomes, we propose a framework that describes the process of reaching common understanding during sketching in design teams (Figure 6).

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